SONIFICATION AS ART: DEVELOPING PRAXIS FOR THE AUDIFICATION OF COMPOST

J. no.e Parker

University of California Riverside
Music Department
900 University Ave, Riverside, CA 92507
jpark096@ucr.edu

ABSTRACT

This paper introduces compost as a rich site for creative exploration and expression via the medium of sonification art in the context of *Composing [De]Composition*, a large-scale audiovisual installation/performance work to be presented at University of California Riverside's *Culver Center for the Arts* from June-October 2015.

Here, the author non-reductively describes the multi-agential and poly-temporal nature of compost through detailing the evolution of an artistic praxis involving: the observation, audification, and sonification of compost temperatures; the development new sensing methods for data-collection; and sound-mapping strategies. The main observable driving the project is incalescence—the heat generated by the composting process. Audification of this biological process brings a perceivably silent activity into the tangible reach of human hearing. The collection and real-time audification of temperature data using a custom interface to route sensor data to MAX/MSP enables listeners to better understand the complex ecology of a heterogeneous mass that is simultaneously decomposing, supporting a myriad of life forms while also enabling the bioavailability of macronutrients to the soil. In addition, the recontexualization of temporally-based temperature data into sound creates fertile ground for exploration in the compositional realm, as the collection of data over time depicts inherent patterns occurring in the systems analyzed, while the basis of music also builds upon the use of patterns (pitch based, rhythmic) through time. Sonification of these patterns enables the composer/sound artist to create compositions in partnership with her subject/phenomenon of study.

1. INTRODUCTION

Citing Idhe's material hermeneutics and defining sonification as a point of departure, "For science, or art, to be experienced, it must take into account human embodiment … if the phenomenon lies beyond our capacity, then only by being technologically transformed can it come into our range" [1]. The translation of data into sound is called sonification, "which can be defined as the data-dependent generation of sound in a way that reflects objective properties of the input data. Sonification … research takes place [through an interdisciplinary process that includes] physics, acoustics, psychoacoustics, signal processing, statistics, computer science, and musicology" [2].

Composing [De]Composition, is a practice-based approach toward compost and the sonification of data collected from it as a site of creative expression. The project is a response to the growing body of art/music based on environmental data, especially with regard to the issue of global warming. While many works dealing with data sonification engage with big data and large scale environmental issues, the approach used for *Composing [De]Composition* is to collect data from a more "ordinary" and accessible source.

The primary material for the *Composing [De]Composition* is decomposing organic matter—compost—a complex, living matrix whose elaboration permeates the installation and performance. Sonification of this biological process brings a perceivably silent activity into the tangible range of human hearing through the collection and real-time audification of temperature data using a custom interface to route sensor data to MAX/MSP. A sound installation featuring two different methods of compost sensing will continually gather and log data on the compost samples over a period of three months. During this time, the installation space will also be used as an active audification research lab where data from the compost samples will be directly used in real-time audification experiments, and the performative possibilities of using the sensor apparatus will be investigated. Visitors to the gallery will experience the audified data thorough a spatialized, eight-point speaker array mapped to mirror the placement of the temperature sensors inside of the on-site compost container.

The recontexualization of data into sound also creates fertile ground for compositional exploration, as the collection of data over time depicts inherent patterns occurring in the systems analyzed, while the basis of music also builds upon the use of patterns (pitch based, rhythmic) through time. Detected patterns in the collected data sets will be used to generate larger rhythmic, tonal, and temporal musical structures for a score-based aspect of the work that will feature acoustic instrumentation for both Western and Indonesian pitched percussion instruments such as marimba, Javanese kenong and gongs, and triangles of varying pitches.

This composition-based facet of the project will premiere during the closing of the exhibition in October 2015 as a live, audiovisual performance piece that integrates data, sonic, and visual materials collected during the year-long research and exhibition period.

The development stages of this long-term sonification art project include:

I) Hands-on research on the aerobic composting process and investigation of how to collect the most meaningful data from the material;

II) Temperature sensing apparatus development and techniques to easily collect, store, and sonify the data;

III) The design and creation of a three-month audiovisual installation at the UC Riverside *Sweeney Gallery* where data collected from compost samples originating on the UCR campus will be audified *in situ*;

IV) Translation of data gathered during the exhibition into scored notation for gamelan, Western percussion instruments, and electronics.

This paper discusses the following four areas of the larger project in the context of sonification art:

1. Developing praxis for sonifying compost as a site of creative expression;
2. The creative process involved in prototyping a temperature and decomposition sensing apparatus;
3. Developing a robust metaphor for mapping parameters directly for real-time audification;
4. Developing real-time sensing performative strategies.

1. SONIFICATION ART

2.1. Prior Work

The aesthetic potential of sonification as an artistic medium has been developed by sound artists like Andrea Polli who made extensive use of sonification techniques in a public sound art installation on climate change. Many artworks based in data sonification engage with big data and issues of global pollution, tsunami waves, war, outer space, train schedules, DNA, etc. Projects of note include sound artist Polli's *Atmospherics/ Weatherworks: the Sonifcation of Meterological Data* (2002) dealing with data on major storms in the New York metropolitan area,[1] Chris Chafe's use of Blackcloud Citizen's Science League's worldwide sensor readings for carbon dioxide levels, humidity, and concentrations of volatile organic compounds from locations including Katmandu, Shanghai and Tokyo to influence different aspects of the musical components of his work, *Smog Music* (2008) [2] [3], and Dombos and Brodwolf's sonification of the Tohoku earthquake off of Sendai Japan in 2011[3].

In contrast to the big data approach in the abovementioned works, New Orleans-based Quintronics and the Robert Rauschenberg Foundation have developed the *Weather Warlock* (2014), an online-streaming, drone-based synthesizer that is driven by real-time temperature, wind, sun, and rain data audified directly by the instrument.[4] *Weather Warlock* listeners worldwide can tune in at any time and listen to a site-specific, real-time climate audification via the synthesizer located at Quintronics' New Orleans base station.

2.2. Compost as a Site of Creative Expression

Similar to the *Weather Warlock*, the approach of *Composing [De]Composition,* is to collect data from a somewhat more "ordinary" and accessible source. Spontaneously generated out of something very unremarkable—lifeless vegetal matter, our left-overs/ food waste /refuse—the biota of compost self-organizes in any place there is a scrap of organic (i.e. carbon-based) matter, moisture and a source of oxygen [4]. The main observable driving the project is incalescence—the heat generated by the composting process.

The choice of compost as a site for exploration stems from a personal 20-year practice of daily food-waste composting in various internationally based sites. An eventual turn toward the deep integration of this somewhat mundane environmental process into my artistic practice first began during a two-year residency at the Indonesian Art Conservatory in Yogyakarta, Java where I began merging seeds sprouting from my garden compost pile into textile hangings and site-specific installation work. Whereas this previous work integrated plant life borne out of personal food refuse, *Composing [De]Composition* begins an investigation into the actual process of decomposition and harnesses its incalescent properties for the generation of sound art.

The project establishes compost as an "actant … a source of action that … has sufficient coherence to make a difference" [5] in the creation of the work itself—thus recontextualizing the product of the somewhat 'ordinary' act of home composting into an artistic material, a muse, and most importantly a collaborator. Through its recontextualized role, the material/textile/biota of compost is revealed as true energetic force of creation. Working with the biota is working at the edge of life and death—what is produced at the end of the human food chain continues on to support millions of smaller life forms who live, eat, reproduce, are eaten, and die at a timescale of a few days or a few months at most—a process transforming nearly everything into nourishment for future plant life.

3. BIOLOGICAL/ MULTI-AGENTIAL ASPECTS OF COMPOST

Briefly, composting is an aerobic biological process that occurs when insects, invertebrates and microorganisms "digest" the carbon of the carbohydrates contained in decomposing organic matter. The use of the term *aerobic* indicates that the organisms involved in this process require oxygen and moisture to live and reproduce. As part and parcel of this carbon- and oxygen-rich "feeding frenzy", the various-sized organisms also generate heat, water vapor and carbon dioxide during the process of respiration. The terms "compost" and "biota" in the context of *Composing [De]Composition* refer to the entire network of biota present during the decomposition process—consisting of decaying vegetal matter, worms, large insects, fungi, and millions of microorganisms.

Common insects found in a compost heap include: fruit flies, ants, earwigs, and black fly larvae, to name but a few. These larger beings can all be seen clearly without magnification. Microorganisms such as fungi and actinomycetes (bacteria that resemble fungi) occur in the outer 10-15 centimeters of a compost pile are also visible to the naked eye. Under 200x magnification, white potworms, and tiny insects such as springtails and mites can be seen in action. Zooming to 400x magnification, larger bacteria—which make up 80-90% of the microbial community found in compost—are visible and the micro-structure of fungi can be more closely examined.

There are two main types of composting—backyard composting and thermophilic composting that occurs at the industrial level. In optimized industrial situations, the life of a compost pile is roughly a few months until the "curing phase" when the oxygen supply is no longer available to the ecosystem and the material becomes a market-ready mulch. The temporal range for backyard composting on the other hand has a much broader spectrum. Home composting most commonly occurs on a much smaller scale and in closed containers for efficiency and matters of public health/city ordinances. In this type of composting, new matter is constantly added to the larger pile/bin and decomposition

1. www.andreapolli.com/studio/atmospherics/
2. http://chrischafe.net/smog-music/
3. https://www.youtube.com/watch?v=3PJxUPvz9Oo
4. http://weatherfortheblind.org/

speed completely depends on the methodology used. Turning the pile every day is the most effective technique to make sure oxygen is supplied to the entire biota on a regular basis, helping to speed along the composting process [6].

4. DECODING THE BIOLOGICAL PROCESS THAT BEST REPRESENTS DECOMPOSITION

Using compost as compositional grist involves a revelatory process of decoding *which* aspects of the heterogeneous mass that best represent it as a whole. At the temporal and geometric scale of human visual perception, compost appears to be in stasis. Daily observation over the period of weeks is required to see color and texture changes. Microscopic study of compost shows the opposite—a hugely dynamic, unstable ecosystem with a large amount of activity among a complex array of life forms.

Oxygen and water must be present for decomposition to be enabled. Monitoring changing moisture levels during decomposition is a simple and easily available way to detect changes in the biota. **"**If adequately aerated, composting material with moisture content between 30% and 100% will be aerobic" [7].

Obtaining accurate oxygen levels in the biota, however would require a laboratory-like closed system to monitor the pile for a total decrease in oxygen as the biota consumed it and returned carbon dioxide in the respiration process. Constructing this type of setup would be complicated and conflict with the requirement that the biota be frequently turned so that a constant supply of environmental oxygen is supplied.

On the macroscopic scale, compost can be thought of as a site of oxidation of organic compounds. Oxidation stabilizes these compounds making them available for use as a soil supplement for future plant propagation. Carbon in the form of carbohydrates is one of the main ways the organisms get energy, and the nutrients made available by the biota most important to improving soil health include nitrogen, phosphorus, and potassium (NPK).

Monitoring the levels of NPK that are produced by the biota also presents its own set of drawbacks. Current affordable soil nutrient testing is not sensor-based, rather, the technology requires that a small sample be removed from its context and placed in an aqueous solution—only to obtain approximate levels (i.e. high, medium, and low)—a system too cumbersome and inexact to be of interest here. In addition, components such as carbon (in the form of carbohydrates), potassium, nitrogen and phosphorus represent inputs and outputs to and from the system and do not well represent the decomposition process itself.

Contrastingly, decomposition and temperature are tightly coupled. Heat accelerates microbial functions and also acts to change the microbial ecology. The efficiency of composting doubles for every 50˚F increase in temperature. There are two temperature dependent, yet distinct stages of the composting cycle: 1) The "active" stage which itself has two phases; and 2) The curing stage. The "active" stage of composting occurs between 32˚ and 149˚F. When the pile is at temperatures between 32-104˚, mesophilic bacteria predominate. Backyard composting operations remain at this stage unless there is a multi-container setup where no new vegetal material is added to one of the containers, allowing the compost to steadily increase in temperature. Above 104˚, the mesophiles begin to die off and thermophilic bacteria take center stage. These heat-loving microbes can survive in temperatures up to 155˚F. Pathogens and seeds in the compost pile are terminated when the pile reaches level of 131˚. Above 160˚ thermophilic bacteria dieoff begins, and the compost becomes sterile. Temperatures decrease when when oxygen is no longer supplied signaling the final stage of the compost cycle.

Figure 1: A rotating barrel aerates the composting process.

5. SENSING

5.1. Prototyping the Temperature Sensing Apparatus

As a precursor to the development of the project's sensor apparatus, a handwritten account of daily compost temperatures was recorded for a period of 45 days between December 8, 2014 and January 21, 2015. The composting container used for the study is located outside my home on the UC Riverside campus (Figure 1). The design of the compost bin is a rotating, barrel-shaped ventilated plastic container suspended on a metal stand. The light brown lids located on the top and bottom of the barrel are removable so more vegetal matter can be added to the composter.

Over the course of the prototyping period, the number of

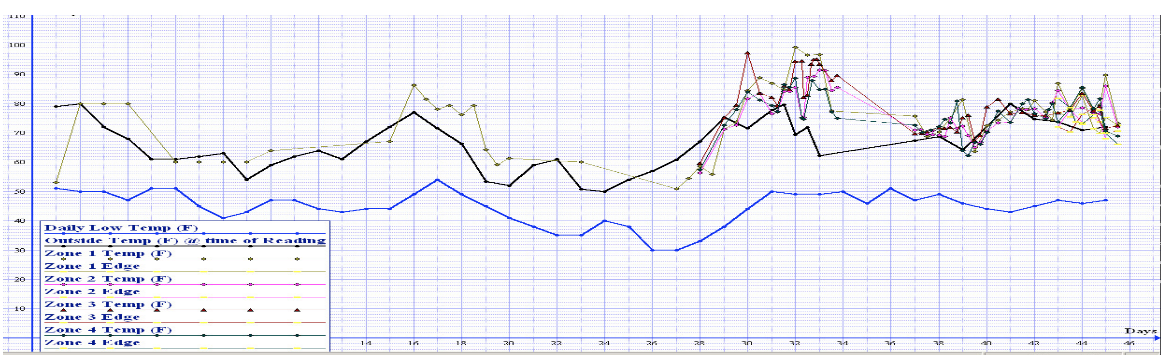

Figure 2: Compost temperatures juxtaposed against daily high (black line) and low (blue line) temperatures over a period of 45 days. The temperature sensing apparatus is first used at day 28, showing multiple temperature readings.

regions monitored for changes in temperature rose in total from one to eight as the tools of data collection became more refined. At first, an analog meat thermometer was used, but it was difficult to achieve accuracy with it. Next, a four-inch digital meat thermometer was substituted. Its improved accuracy and relatively instantaneous speed afforded the ability to divide the compost bin into four equal quadrants, and record a distinct compost reading from each zone in a relatively short time period.

The temperature data collected during the 45-day period is visualized graphically in Figure 2 above, with the horizontal axis representing each day of the study (1-45) and the vertical axis as temperature in degrees Fahrenheit (0-110). Each day's temperature reading(s) is a direct reflection of the compost temperature of that day. The lowest temperature of the day's reading is illustrated as the bottom blue line, and the outside temperature at the time of the compost readings is plotted as the strong black line. Figure 2 also illustrates the temporal trajectory in my process of learning how to read the compost with increased accuracy. The increasing collection of graphic information underwrites the recognition of the mass as a dynamic homogeneity

Figure 3: The sensing prototype (right) and a paper Ag-NP sensor (left) buried in the compost bin.

rather than as a fixed mass. The singular green line spanning from day 1-27 shows one temperature reading representative of the entire pile—a direct result of the inadequacy of the temperature-reading tool.

At day 28, the digital thermometer is first employed. The tool's increased accuracy enables quick temperature readings from multiple areas within the span of a few minutes. With faster and more accurate temperature sensing, it is deemed valuable to begin to monitor the biota both pre- and post aeration. Therefore, beginning at day 29, the mass is monitored both before and after fully turning the pile four to five times, yielding two different temperature readings per day. Rapid temperature changes were recorded immediately after turning the pile as the act of turning the compost triggers a race toward temperature equilibrium throughout the biota.

The increased amount of information is reflected on the graph by inclusion of multiple points for each day. There is no attempt to give the multiple readings an accurate temporal value in the graph time line, instead, the points divide the day into roughly equal segments. At day 43, it is observed that there is a large difference in temperature at the most extreme areas of the quadrants themselves—readings taken at the center of the compost bin are almost consistently ten degrees higher than readings taken at the outer edges of the bin, thus driving the total number of temperature zone conditions needing to be recorded to 8 (two per zone).

The 45-day compost temperature study was not only crucial in answering questions regarding the numerical temperature range of the compost, but the process also teased out an integral question needing to be addressed in the design of the sensor interface. During this stage, the necessity of designing an array-based temperature sensing apparatus was made absolutely clear, in order to reflect the non-homogenous character of compost. Conclusions reached at the end of the temperature observation period include: 1) Given the heterogeneous character of the compost itself, the deployment of sensors inside of it can only detect the conditions in localized areas at a given moment in time; 2) In order to monitor the biota as more of a "whole" phenomenon at any given moment, the sensing apparatus must be able to measure multiple zones simultaneously. The ability to simultaneously measure eight temperature "zones"—including points at the compost's edges and its core—is enough to produce a basic profile of the pile; and 3) Temperature fluctuations observed immediately after aerating the pile prove to be an avenue for the instrumentalization of the biota by measuring and audifying this phenomenon.

5.1 Sensing Decomposition

Finally, the process of working so closely with the biota also raised the question of how to sense the process of decomposition itself. The compostability of a silver nano-particle (Ag- NP) circuit ink-jet printed directly onto photo paper and placed directly inside the compost bin is being observed at the time of this writing (Figure 3, left). As the biota degrades the ink, the Ag-NP pathway is broken down and the resistance of the sensor goes up. Tests show successful decomposition was achieved after only 24 hours inside the biota. This speedy result shows promise toward the further development of paper sensors as an added sensing interface.

6. PARAMETER MAPPING–SONIFICATION AS ART

Composing [De]Composition joins the seemingly unconnected practices of home composting and aspects of new media art, electronic music, and sound design into a long-term artistic project. The audio-visual installation in the *UCR Sweeney Gallery* will allow guests a direct window into methodologies for the collection and audification of temperature data emitted by the biota *in situ*. During the exhibition, the compost will be audified on a continual basis—rendering a non-stop, biota-driven "performance" as real-time audification of the temperature variations within the self-organizing mass make the silent process of decomposition tangible on a human scale.

The primary challenge inherent in sonification art—this work included—is for the artist to develop creative and meaningful sonic metaphors to express data pertaining to usually silent activities on the human scale. "The essence of metaphor is understanding and experiencing one kind of thing in terms of another," [8] therefore it is imperative to form a robust audible metaphor that will successfully carry the audience into the unseen data-world [9].

Figure 2 above illustrates the temperature of the compost during the 45-day outdoor study as ranging between 55˚ and 99.2˚F—numerical values that fall neatly into the audible range of human hearing when directly translated into frequency. Therefore, a direct, linear mapping of the biota's temperature profile to frequency is an intuitive choice in the context of *Composing [De]Composition*. Berger and Grond also speak of a simple and direct mapping of temperature to frequency or pitch [10].

I will first describe the process involved in the derivation of the individual, temperature-based soundwaves, their projection into the gallery space, and then provide aesthetic justification for the direct mapping. To create the real-time audification using MAX/MSP, a wavetable was constructed consisting of eight partials determined by each temperature sensor's data. Scaling between -1 and 1 was performed in order for the numerical data to better conform to the partials of a complex soundwave. As a result, the lowest observed temperature obtained during the 45-day study (50°F) equals -1 and the highest observed compost temperature (120°F-obtained after the 45-day study) equals 1. This scaling does not affect the resulting sound in any way. Each temperature sensor's wavetable is driven by a phasor~ object in MAX/MSP which provides the wavetable a signal input/phase that cycles between 0 and 1. The temperature value is sent as frequency through the resulting wave table described above and amplified by its own distinct speaker in the gallery space. In addition, a biodegradable paper sensor will be placed near each of the eight temperature sensors in the compost bin and the changing resistance resulting in the deterioration of the silver nanoparticle circuit will be used to control the envelope of the corresponding temperature-driven signal. Each speaker will output a single frequency matching the temperature detected by its sister sensor from above the exhibition space. The compost temperature apparatus / computer / MAX/MSP setup in the gallery will also include a monitor-based visual display of the eight temperatures being audified in the same arrangement as the temperature sensors and speakers to help visitors understand their sonic environment better.

Although sound surrounds us throughout our day-to-day lives, many people probably do not have the opportunity to imagine the sounds in our environment as possessing many distinct frequencies. The installation is designed to enable visitors to experience sound and data in an interesting and analytical manner. Therefore, from a pedagogical perspective, keeping the temperatures and frequencies tightly aligned in a direct way can help visitor/listeners understand experiencing sonic frequencies as/in Hertz.

The purpose of mapping the biota's temperature profile linearly onto audio frequency in the audification is not expressly meant to enable a listener to accurately name the temperature/frequency emitted from a single sensor, however. Although the sound of the frequency mapping of any particular area of the biota will be more focused when listeners are positioned directly under a temperature sensor's corresponding speaker in the gallery area, the composite eight-point soundscape will be far too complex for the listener to accurately analyze each of the eight distinct temperatures singularly. Rather, the complex soundscape sonically and aesthetically represents the real-time temperature state of the entire biota—translating it into an eight voiced, spatialized, drone generator.

I feel that by directly translating temperature to frequency using a linear mapping keeps the data closest to its original form and avoids the audification from sounding overtly musical. Human hearing is sensitive enough to detect even a few Hertz difference between frequencies, perceived as acoustic beating, and this mapping for the audification turns the possibility of having two or more sensors with data readings in a close range into a sono-textural advantage.

On the human scale, the spectrum of temperature ranges elicited from the biota spans between slightly cold (50°F) and those dangerous to human health (~110-120°F). Contrastingly, when this data is directly translated to frequency, the resulting signals fall into the mid-low frequency range of human hearing—a sound spectrum that is quite harmless to humans and can be roughly compared to the range of between Ab/A1 and the second octave of a piano. For example, the ambient room temperature value of 70°F translated into Hertz is only a few microtones above the piano's Db2 (69.3 Hz) while the higher end of the projected compost temperatures end a few microtones below B2 (123.5 Hz).

Obviously, a direct, linear mapping of temperature to frequency as utilized here does not immediately correlate with the human experience of the two distinct phenomena of temperatures and sonic frequencies found in this range. However, I have decided to maintain this direct relationship between temperature and frequency from the viewpoint that use of low frequency sounds conceptually aligns with the ideas that on the human scale: a) composting is a relatively slow process, aligning with the slow movement of low frequency soundwaves; and b) the audification is measuring the biota's terranean-based process of soil creation—an activity that is normally silent and takes place underneath our feet, whereas high frequency sounds are produced by birds and larger organisms that fly above the ground and our heads.

8. SOUNDSCAPE

Walker and Nees have established that "soundscapes—ongoing ambient sonifications—have been employed to promote awareness of dynamic situations. Although the soundscape may not require a particular response at any given time, it provides ongoing information about a situation to the listener" [11]. Visitors to the gallery can hear what happens as the biota is left to its own devices—as the partials slowly, perhaps even imperceptibly change over time.

While the abovementioned 45-day temperature data study was conducted in outdoor conditions, the main installation will be in a temperature-controlled, gallery setting. Inside the gallery, visitors will be immersed in an eight-point, spatialized soundscape created and controlled by the temperature sensors. Each of the eight speakers will mirror the placement of a corresponding temperature sensor in the composting container, as Figure 4 below illustrates.

Each temperature/partial signal will be sent to its dedicated speaker inside the installation space placed in an eight-point array mirroring the placement of the temperature sensors inside the biota. This allows visitors to create their own audio "mix" by physically moving around the room underneath the speakers. In this way, the real-time frequency-based parameter mapping of temperature data to each speaker can be very easily understood as differences in temperature/pitch by a visitor moving from one speaker to the next inside the installation. According to Grond and Hermann, "the tight relation between action and perception is important for … engagement with the sound: [if] the sound is clearly anchored to a physical cause … this closed loop allows us to correctly interpret the information carried

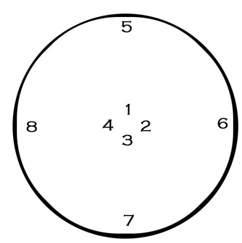

Figure 4: Positioning of sensors inside the biota.

by the impulse response in relation to impact" [12]. For example, if the temperature in one area of the biota is higher or lower than in another, the frequency of the partial emanating from the speaker related to that specific zone reflects that difference, sounding higher/lower. Moreover, the spatialization of the complex waveform into its eight individual partials through eight speakers situated around the gallery space enables the visitor to imagine herself moving around, inside and between the different zones of the compost container.

As the indoor installation has yet to happen at the time of this writing, I can only postulate as to the final soundscape that will be created by the biota indoors based on my findings from the outdoor study and already established temperature research on other indoor composting setups. According to Trautmann et. al, "The heat production [of a compost pile] depends on the size of the pile, its moisture content, [and] aeration … additionally, ambient (indoor or outdoor) temperature affects compost temperatures … A well-designed indoor compost system, [greater than] 10 gallons in volume, will heat up to 40-50°C [104-122°F] in two to three days" [13].

Taking this information into account, the possible temperature variation of the compost will probably fall somewhere between the ambient room temperature of the gallery space (~70°F) and the highest temperature range set out by Trautmann for indoor composting (122°F). According to the 45-day outdoor study, it is probable that the difference in temperature readings among the eight areas of the biota will range between 0-20°F at any given moment.

Figure 5 below[5] is a monaural recording of the sonification of temperature data logged at the center of Zone 1 in the compost pile on days 43-45 of the outdoor study. Note: The outdoor study occurred prior to the development of the temperature sensing apparatus, so I have created an after-the-fact sonification to illustrate the data. Figure 6 below illustrates the sonogram of the sonification. The example has six 10-second sections, demarcated by quarter-second silences between them. Each day is represented by two temperature readings taken at approximately 11am and 3pm each day. The first two sound examples emulate data logged at day 43, the second two represent day 44, and the remaining two at day 45. Looking at the sonogram for day 43, 11am one can see the fundamental frequency as the bottom of the sonom and the seven resulting harmonics above it. The sonic material represented in Figure 5 is an example of the type of audification that will be sounding over time from the speaker associated with the temperature sensor inside of the compost bin in the gallery—although there will be no silent pauses in between data points. Listening to each day's audification in series effectively illustrates the temperature changes that occur in one area of the compost over time.

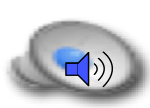

Figure 5: Sound file of compost Zone 1/ Center temperature data sonification logged during days 43-45 of the outdoor study.

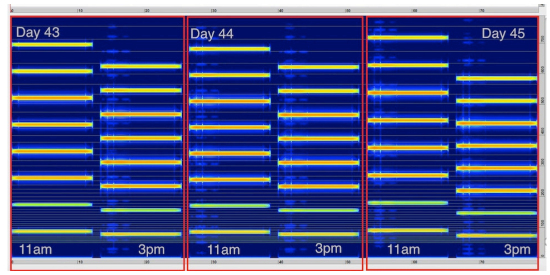

Figure 5.1: Sonogram of Zone 1/Center temperature data days 43-45 mapped to frequency—showing fundamental frequency and 7 yellow partials. Frequency range depicted spans from 0 to over 700 Hz.

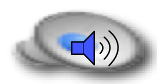

Figure 6: Sound file of all compost temperatures in Zones 1-4 during days 43-45 of the outdoor study.

Similarly, Figure 6 above is a monaural sound file created from sonified data logged in Zones 1-4 of the biota between Days 43-45. Unfortunately in this monaural example, proper spatialization of each signal is not possible as it will be in the actual gallery setting. Figure 6.1 below represents the sonogram of sonic material in Figure 6. All temperatures logged on days 43-45 were below 100°F and are represented as the bottom band of each sonogram listed. Upon closer inspection of the sonogram at day 43/11am (Figure 7), one can see the complex textures resulting, especially in the middle-ranged partials, due to acoustic beating that occurs when all zones of the biota are audified simultaneously,

Like the biota itself, the audification reveals much more than its own basic ingredients, as the sonograms show. The acoustic beating that occurs between closely-related temperatures create a thick, subrhythmic texture, multiplying the interiors of the eight waves in a way that can directly refer to the uncountable organisms that are busily at work inside the compost.

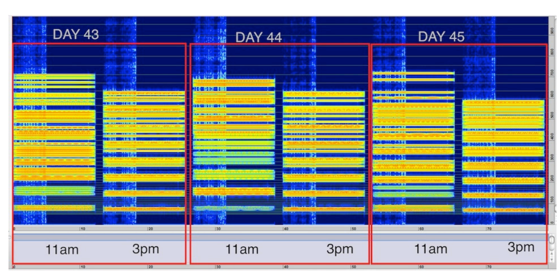

Figure 6.1: Sonogram of Zones 1-8 temperature zone data logged during days 43-45 of the outdoor study. Frequency range depicted spans from 0 to over 700 Hz

Aesthetically speaking, the resulting soundscape can be described to have a very subterranean and insect-like quality. In fact, I have experienced naturally occurring insect soundscapes similar in texture to this audification during the predawn hours while living on the tropical island of Bali, Indonesia.

[5] If unable to hear listening examples in Figures 5 and 6 directly inside of the document, please go to https://soundcloud.com/no-itome-sakana/sets/icad-2015-figures-5-6

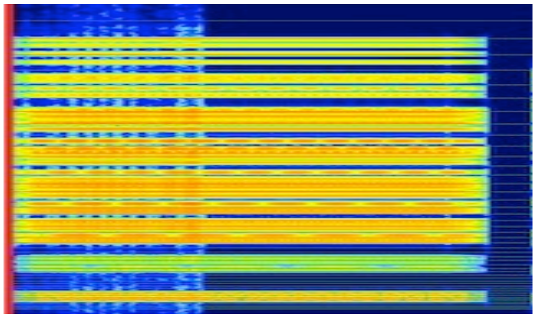

Figure 7: The sonogram illustrates the biota's day 43/ 11am audification in closer detail. Orange and yellow colored areas show acoustic beating.

7. PERFORMATIVITY

The act of audifying temperature relationships within the biota can be seen in itself as a routinized, performative, and multi-layered process. The first layer of this process is one in which temperature data is generated solely by the self-organized biota and directly expressed through the temperature-to-frequency audification. This human-aided process entails: 1) Setup of the computer/sensor interface; 2) Don rubber gloves to avoid ingestion of pathogens; 3) Insert temperature sensors into the eight distinct areas of the compost container; 4) Turn up the volume of the sound system; 5) The compost reveals its heterogeneous temperature state via a complex waveform.

A second, human interaction-based layer to the sonification of the biota occurs in the daily opportunity for gallery visitors to turn the compost bin and witness how the audified sonic landscape is different before, during, and after aerating the mass. The design of the sensing apparatus at the time of writing necessitates its removal from the biota prior to manually aerating the pile. Hence, a disruption in the biota's continual, complex drone manifests as an opportunity for visitors to hear temperature differences between the biota, the room temperature of the gallery, and the way aerating the biota affects it. For example, while removing the sensors from the biota to turn the compost bin results in the sonification of the current room temperature of the gallery, oxygenating the biota by turning it results in an arpeggiation of the temperature partials as they race to return to equilibrium, albeit a heterogeneous one, within the container.

A third, temporally-based layer to the sonification of the biota manifests as a headphone-oriented interactive listening station situated inside the installation—allowing visitors access to past compost audifications. Here, the visitor can listen to and compare any number of earlier temperature states of the biota and also create virtual sonic pathways navigating between the different temperature zones of one audifcation via a computer mouse and LED display-based representation of the compost pile.

9. FUTURE DEVELOPMENTS AND CONCLUSION

Sonification art enables rich, multifaceted, entrainment practices that challenge artists, scientists and engineers in a collaborative process to create practical strategies and robust metaphors for the translation of numerical information into an understandable, sonic form for the greater public. For example, abstraction of the concept of "climate" and the size of the problem of global-warming enables people to disengage personally from forming a sustainable solution. *Composing [De]Composition* is a sonification art project that engages the greater community through building an public interface—the living laboratory/installation—that serves as a platform not only for introducing visitors to the complexities of compost, but also for highlighting to them how to increase one's own day-to-day sustainability efforts through understanding and readjusting our own practices of organic waste disposal.

Composing [De]Composition has deepened my artistic and intellectual engagement with compost and I anticipate a further broadening of this commitment when the project is fully installed in the gallery. The multifarious processes inherent in developing the project as sonification art have resulted in a rich entrainment practice, including: a study of the biological aspects of compost and the composting process itself; developing praxis for compost-sensing; designing and building a sensor apparatus; computer programming and sound design; sound installation design; and aestheticizing compost into a gallery setting.

Future developments for the project include:

1) Continued investigation in the development of the paper-based, biodegradable sensors mentioned above;

2) Accenting a data point as it adjusts with a short (750 milliseconds) burst of amplitude in the speaker audifying the corresponding sensor. Combined with the slowly evolving temperature changes themselves, the resulting short flare in a particular speaker's amplitude will enable listeners to locate which of the temperature sensors are changing at any given time, resulting in a dynamically morphing audification indicating localized changes;

3) Sensing of moisture content. "Moisture content also affects temperature change—since water has a higher specific heat than most other materials, drier compost mixtures tend to heat up and cool off more quickly than wetter mixtures, providing adequate moisture levels for microbial growth are maintained"... "If adequately aerated, composting material with moisture content between 30% and 100% will be aerobic … ideally, home compost piles should contain 40 - 60% moisture" [14]. The moisture level at any given moment in time can act as a scaling factor for the compost temperature data on the whole. For example, if the moisture sensor reads below 30%, all frequencies in the audification will be lowered by a factor of moisture% 0.1, (30 x 0.1)—decreasing by a factor of three, thus suddenly and clearly indicating—with a dramatically lowered frequency range—the biota is at an anaerobic moisture level and should be turned or more wet material added to supplement the oxygen supply; similarly, if moisture rises above 60% or more, the resulting audification will raise 6x, 7x, 8x, etc., depending on the moisture reading, to signify that the pile is too wet and must be aerated more regularly;

4) Consideration is currently being given to the development of eight gamelan-based one-element Earcons to represent each temperature sensor in the biota. The Earcons can act to alert visitors in real-time both not only when but how the localized temperature sensors experience a change in value—as singular, directional (forward or reverse), impulse-based gamelan instrument sounds. "One-element Earcons are the simplest type and can be used to communicate a single parameter of information. They may be only a single pitch or have rhythmic qualities" [15].

Using gamelan instrument sounds as Earcons aligns with my intention to develop sonification-based music compositions for Javanese gamelan instruments toward the end of the exhibition. In addtion, gamelan-based Earcons can serve to aid visitors with less frequency-sensitive hearing to also be able to enjoy and sense the normally silent changes in the compost.

In closing, as in developing a relationship with any new musical instrument, compositional technique, or even composting, one must advance to the point in the learning process of how to use the materials and processes involved successfully, and even creatively. In order to sustain the data-driven aspect of the larger artistic project, there arose a need for developing a stable, systematic method for conducting and recording temperature readings. This has been afforded by the development of the temperature-sensing apparatus. As a result, the affordances of the sensing apparatus introduced new avenues for the instrumentalization of the biota by measuring and audifying temperature-related phenomena. Finally, the human physical actions requisite in navigating the gallery-based temperature-driven sound installation itself and in maintaining aeration throughout the compost drives this compos(t)er to work toward the development of a wider repertoire of gesture-based interactions between the public and the biota.

10. ACKNOWLEDGMENT

I am deeply thankful to Adrian Freed at UC Berkeley's Center for New Music and Audio Technology for his invaluable help in developing the project's sensing apparatus and also for his enlightened insights into sensing compost. I am also grateful to UC Riverside's Professor David Crohn for sharing his knowledge on composting and allowing me attendance in his Spring 2014 Environmental Science lectures, Tyler Stallman, artistic director of the UCR Culver Center for the Arts for providing in-kind and monetary sponsorship, and Professor Ian Dicke for his mentorship, constant encouragement and positivity regarding the project.

11. REFERENCES

[1] D. Idhe. *Postphenomenology and Technoscience: The Peking University Lectures.* State University of New York Press, 2009, p. 78.

[2] Algorithmic Composer. "Sonification–Algorithmic Composition," *The Algorithmic Composer Blog,* entry posted May 14, 2012. http://algorithmiccomposer.com/2012/05/sonification-algorithmic-composition.html. (accessed January 10, 2014).

[3] R. Kwok. "The Sounds of Science". *Stanford Magazine*. January/February 2012. http://alumni.stanford.edu/get/page/magazine/article/?article_id=46481 . (Accessed January 8, 2014).

[4] M. De Landa. Uniformity and Variability: An Essay in the Philosophy of Matter. *Doors of Perception 3: On Matter Conference.* November 1995.

[5] J. Bennett. *Vibrant Matter: A Political Ecology of Things.* Duke University Press, Durham, 2011, p. viii.

[6] D. Crohn. "Composting and Solid Waste Management". Environmental Sciences Lectur*e*, University of California Riverside, 2012.

[7] N. Trautmann, T. Richard, and M. Krasny, *The Science and Engineering of Composting.* Website. Cornell Waste Management Institute, Department of Crop and Soil Sciences. Cornell University, Ithaca, NY, 1996. http://compost.css.cornell.edu/monitor/monitortemp.html (Accessed May 17, 2015).

[8] G. Lakoff and Johnson. *Metaphors We Live By*. University of Chicago Press, Chicago, Illinois, 2003, p. 5.

[9] B. Walker and A. Nees. "Theory of Sonification". *The Sonification Handbook.* Thomas Hermann, Andy Hunt, John G. Neuhoff (Eds.) Logos Verlag, Berlin, Germany, 2011.

[10] J. Berger and F. Grond. "Parameter Mapping Sonification", *The Sonification Handbook.* Thomas Hermann, Andy Hunt, John G. Neuhoff (Eds.) Logos Verlag, Berlin, Germany, 2011, p. 363.

[11] B. Walker and A. Nees. "Theory of Sonification", 2011, p. 20.

[12] F. Grond and T. Hermann. "Aesthetic Strategies in Sonification". *AI & Society* vol. 27, 2012, p. 214.

[13] N. Trautmann, et al. Ibid.

[14] Ibid.

[15] D. McGookin, and S. Brewster. "Earcons" *The Sonification Handbook.* Thomas Hermann, Andy Hunt, John G. Neuhoff (Eds.) Logos Verlag, Berlin, Germany, 2011, p. 340.